Biophysical Analysis of Biosignals: Theoretical Background



K. Kozlíková

© Katarína Kozlíková, 2016

Biosignal

- During the process of diagnosis, it is necessary to obtain **information** about the patient's condition
- Information about functioning of an organism is encoded in its **analogue manifestation**
- Material carrier of the information is a **signal**
- **Biological signal** (biosignal) is any material manifestation of information on an investigated biological system
- **Biosignals** improve the characteristic of a given system, therefore, they **form the basis of all diagnostic methods**

© Katarína Kozlíková, 2016

Displaying and recording measured values

- Processing of biosignals
  - Receiving biosignal
  - Amplification and pre-processing of signals
  - Displaying and saving of measured values of biosignals
    - From the point of view of form
      - Numerical
      - Pictorial
      - Graphical
    - From the point of view of archiving period
      - Transient
      - Permanent

© Katarína Kozlíková, 2016

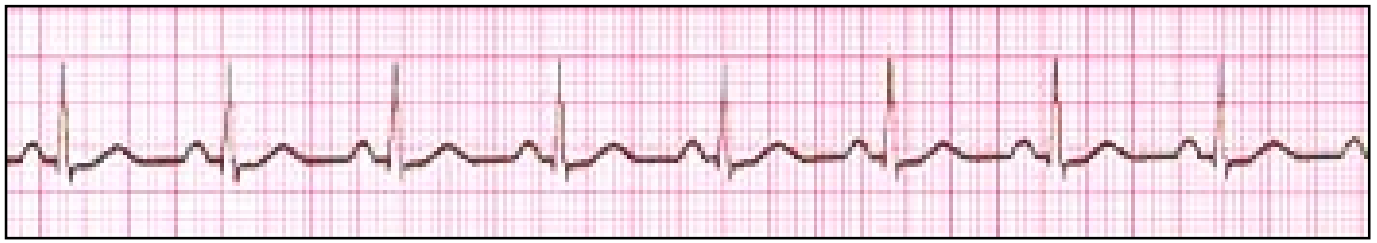
Analysis of biosignals

- From the point of view of output
  - Qualitative
    - Visual
      - The output is a narrative description
  - Quantitative
    - Measurement of physical quantities
      - The output are numbers
- From the point of view of signal complexity
  - Automatic
    - Particularly irregular, complex, non-repetitive signals
  - Manual
    - Simple, repetitive signals
- Therefore, during practical training analysis of an ECG record

© Katarína Kozlíková, 2016

Biophysical analysis of an electrocardiogram (1)

- Electrocardiographic curve
  - Graphical record of the electric activity of the heart (permanent)
  - Relatively simple graph of the dependence of electric voltage on time
  - Quasi-periodic (almost periodic) curve
    - A part of the record repeats regularly (or with only minor changes)

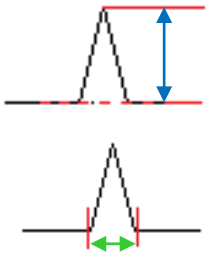


An example of an ECG record of one lead.
Source: author's archive

© Katarína Kozlíková, 2016

Biophysical analysis of an electrocardiogram (2)

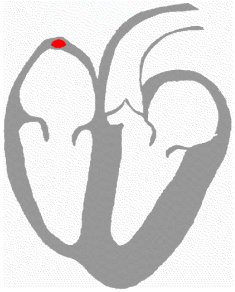
- Biophysical analysis of an ECG curve
  - Simple
    - Amplitude
      - Measurement of height of individual **deflections**
    - Time
      - Measurement of **duration** of individual parts of the ECG curve
    - Frequency
      - Establishing (mean) heart rate
  - More complicated
    - Realted to values obtaind from simple analysis
      - Construction of electric heart axis
      - Analysis of heart rate variability
    - Using special software
      - Spectral (frequency) analysis of ECG

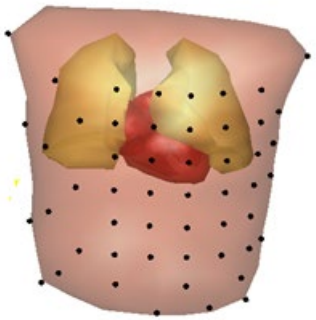


© Katarína Kozlíková, 2016

Biophysical principle of the electrocardiogram

- The heart functions as a pump – it expels blood into circulatory system
- The function of the piston is represented by the contracting ventricular muscle
- Coordination of contraction is provided by the sequence of **action potentials** – sources of electric current – electric heart field is created
- The heart as a **source of electric current** is placed in the human body – electric conductive medium – three-dimensional **volume conductor** that modifies the electric heart field
- Electric heart field is registered at the body surface as electric voltage – potential difference – in form of **electrocardiographic curves**





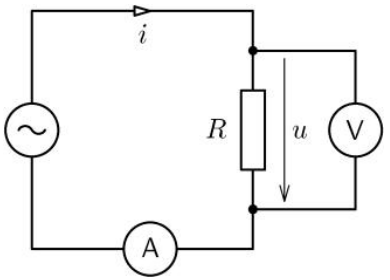
© Katarína Kozlíková, 2016

Physical comment - electric voltage

- Electric voltage
  - Physical quantity
    - Expresses the difference of the electric potential between two points
    - Represents the energy needed to displace the electric charge between these two points in a certain electric field
    - Symbol: U
    - SI unit: Volt [V]
  - Is related to the electric current I [A] (movement of electrical charges) in agreement with Ohm's law

    $U = R \cdot I$

    - R: electric resistance [Ω]



An example of a simple electric circuit to measure the voltage using a voltmeter.

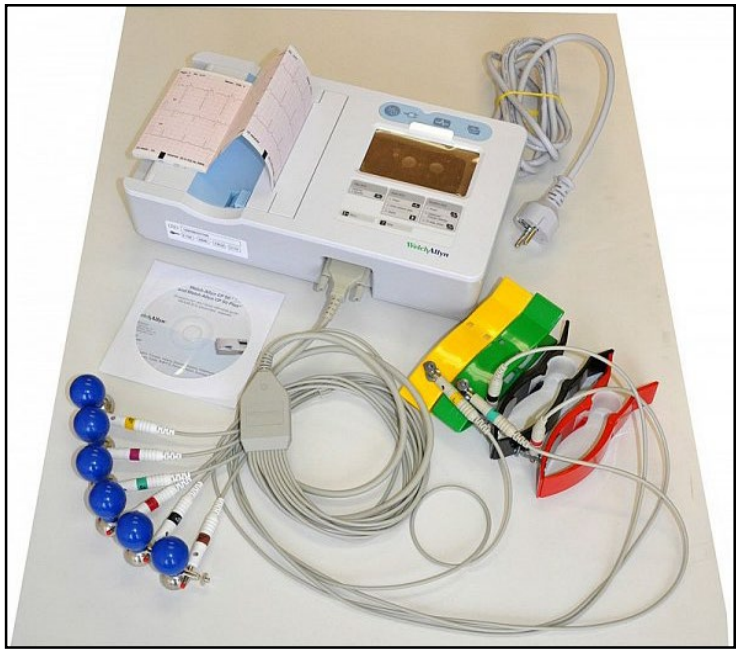
Electrocardiography – basic terminology

- Electrocardiography
  - **A method** of detection, recording and analyses of action potentials of the heart (as being transferred to the body surface)
- Electrocardiogram
  - **Graphical output** of an electrocardiograph that records the electric activity (changes of electric voltage) of the heart during time
- Electrocardiograph
  - **A device** used to record the electric activity of the heart

© Katarína Kozlíková, 2016

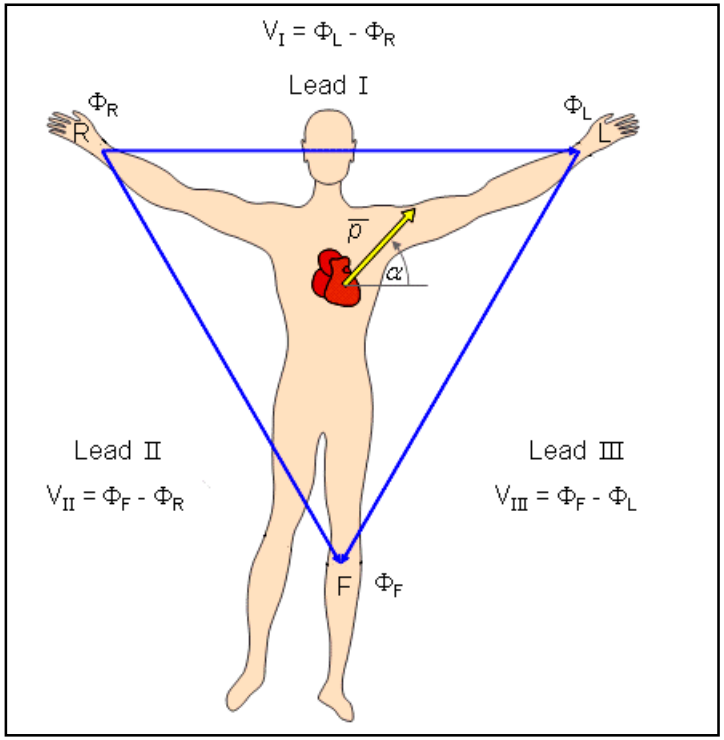
Electrocardiographic leads

- A lead
  - Combination of two conductors and their electrodes, that form with the measuring device (electrocardiograph) a closed **electric circuit**
  - Bipolar
    - Two active (equivalent) electrodes
  - Unipolar
    - An active (different) and a reference (indifferent) electrode



Electrocardiograph and usually used electrodes for standard examination. [Cit. 4. 4. 2011] Available at: http://produkt.sluzby.cz/elektrokardiograph-8738

Bipolar leads – Einthoven triangle



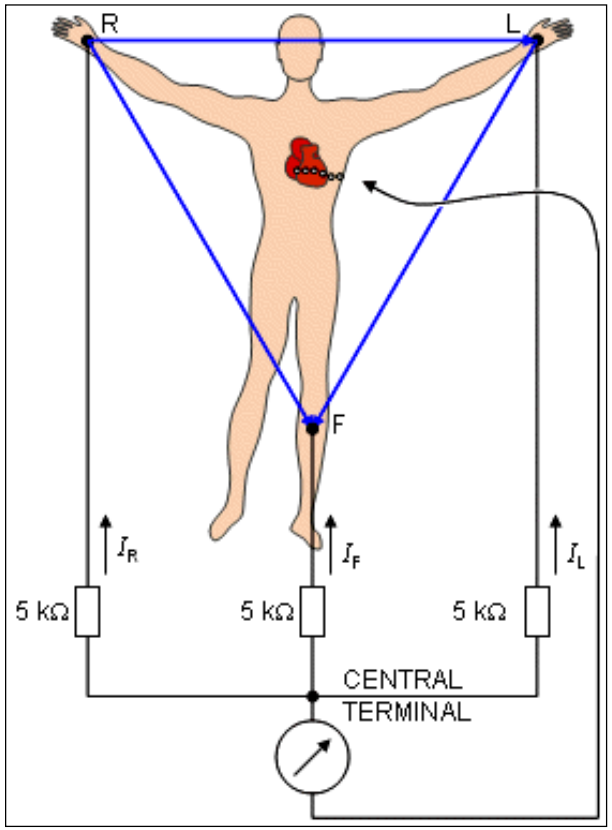
Einthoven triangle.
[Cit. 30. 3. 2011] Available at:
http://www.bem.fi/book/index.htm

- Electric activity of heart
  - Electric dipole (about 90 %)
- Heart position
  - In frontal plane
  - In the middle of an **equilateral** triangle
- Position of electrodes
  - Right hand (R)
  - Left hand (L)
  - Left foot (F)
- Symbols of leads (bipolar)
  - I: $V_I = \Phi_L - \Phi_R$
  - II: $V_{II} = \Phi_F - \Phi_R$
  - III: $V_{III} = \Phi_F - \Phi_L$
- In each instant is valid for voltage V_i (Einthoven's rule)

$$V_I + V_{III} = V_{II}$$

Φ_i : electric potential on the ith electrode

Wilson central terminal



Wilson central terminal . [Cit. 30. 3. 2011]
Dostupné na: http://www.bem.fi/book/index.htm

- Reference electrode pre unipolar leads
- Connection through large electric resistances
  - The total current in the Wilson central terminal has to be zero
    - 1st Kirchhoff law

$$I_R + I_L + I_F = 0$$

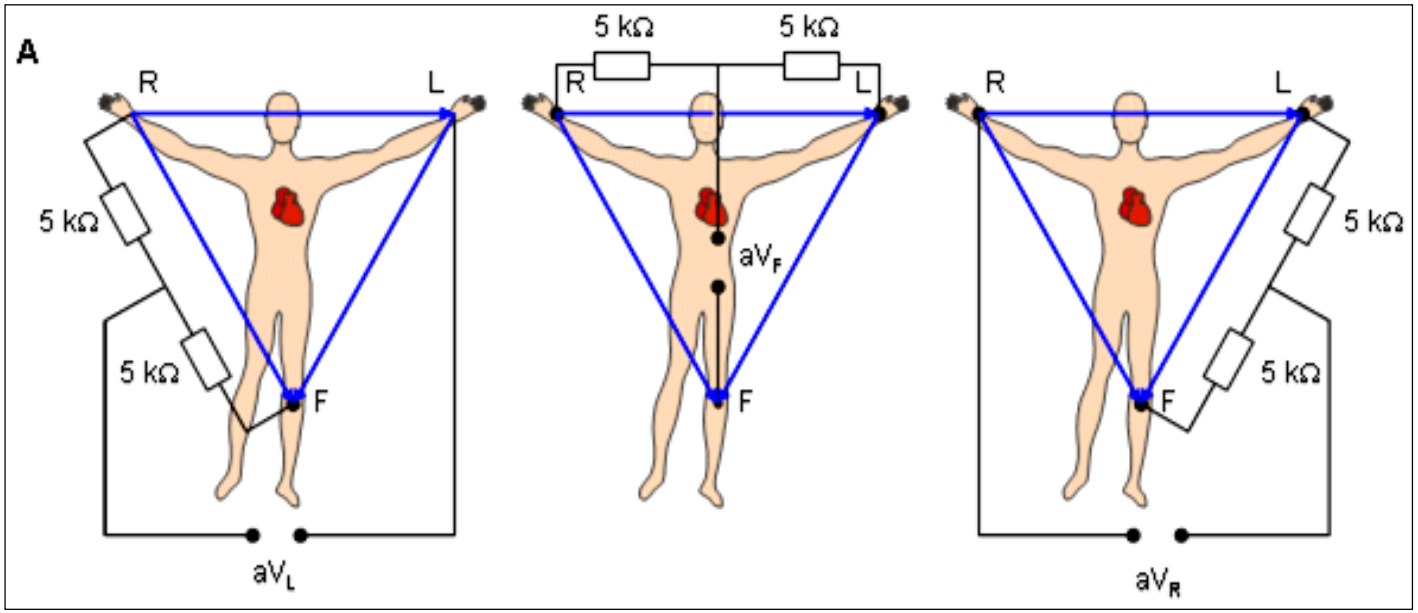
$$\frac{\Phi_{WS} - \Phi_R}{5000} + \frac{\Phi_{WS} - \Phi_L}{5000} + \frac{\Phi_{WS} - \Phi_F}{5000} = 0$$

    - Φ_I: potential at i^{th} electrode
- Potential at the Wilson central terminal
  - Average potential of limbs

$$\Phi_{WS} = \frac{\Phi_R + \Phi_L + \Phi_F}{3}$$

© Katarína Kozlíková, 2016

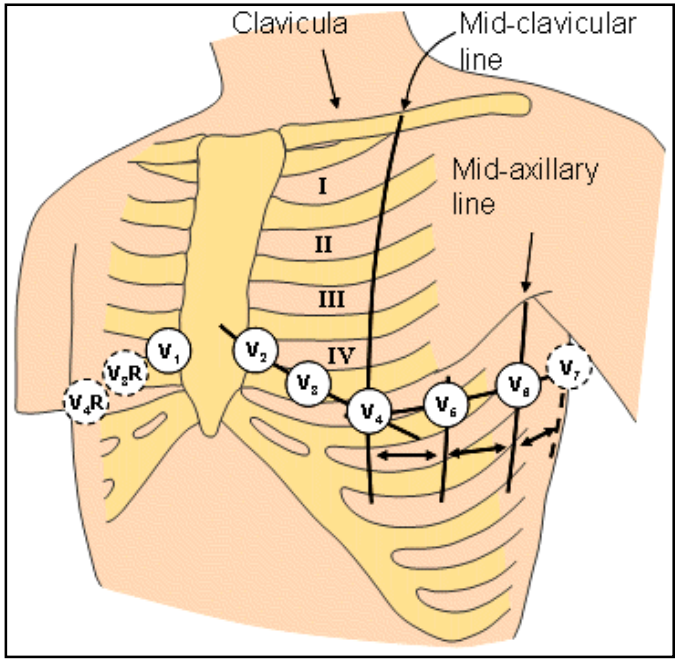
Unipolar leads - limbs



Connection scheme of augmented leads. [Cit. 30. 3. 2011] Available at: http://www.bem.fi/book/index.htm

- Formation
  - Disconnection of one electrode from the Wilson central terminal
- Names and symbols of unipolar leads
  - Augmented (amplified) – aVR, aVL, aVF
    - According to the disconnected electrode
  - Goldberger leads

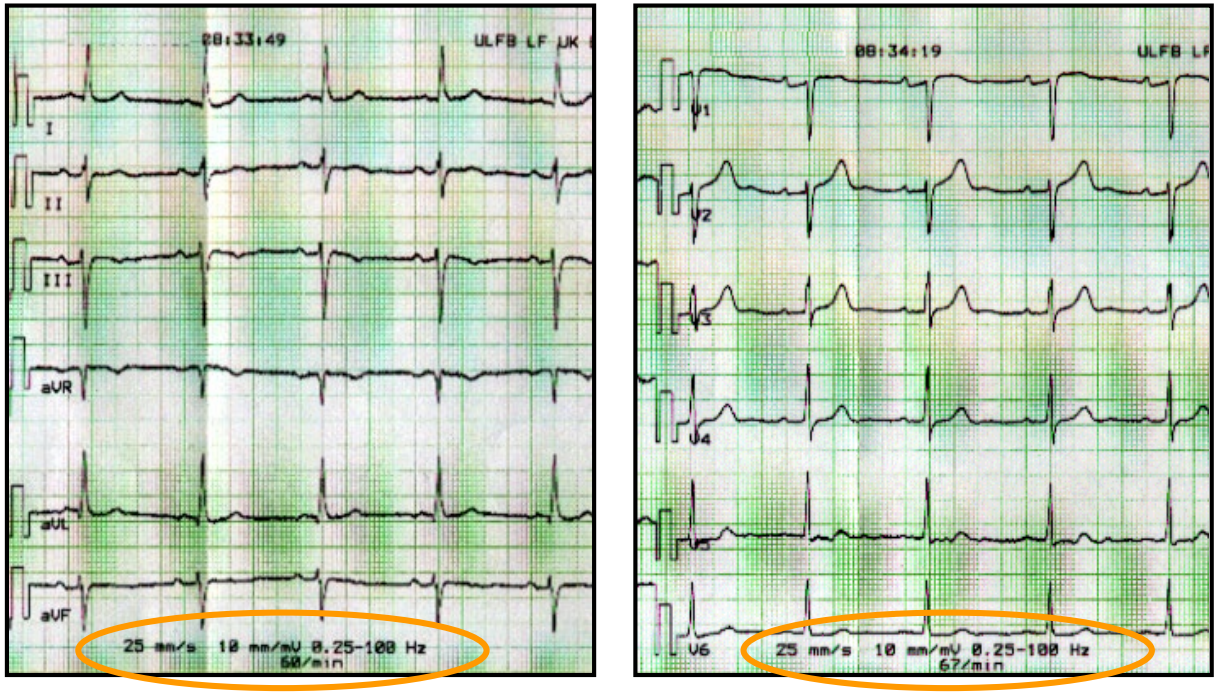
Unipolar leads - chest



Chest leads and their standard positions. [Cit. 30. 3. 2011] Available at: http://www.bem.fi/book/index.htm

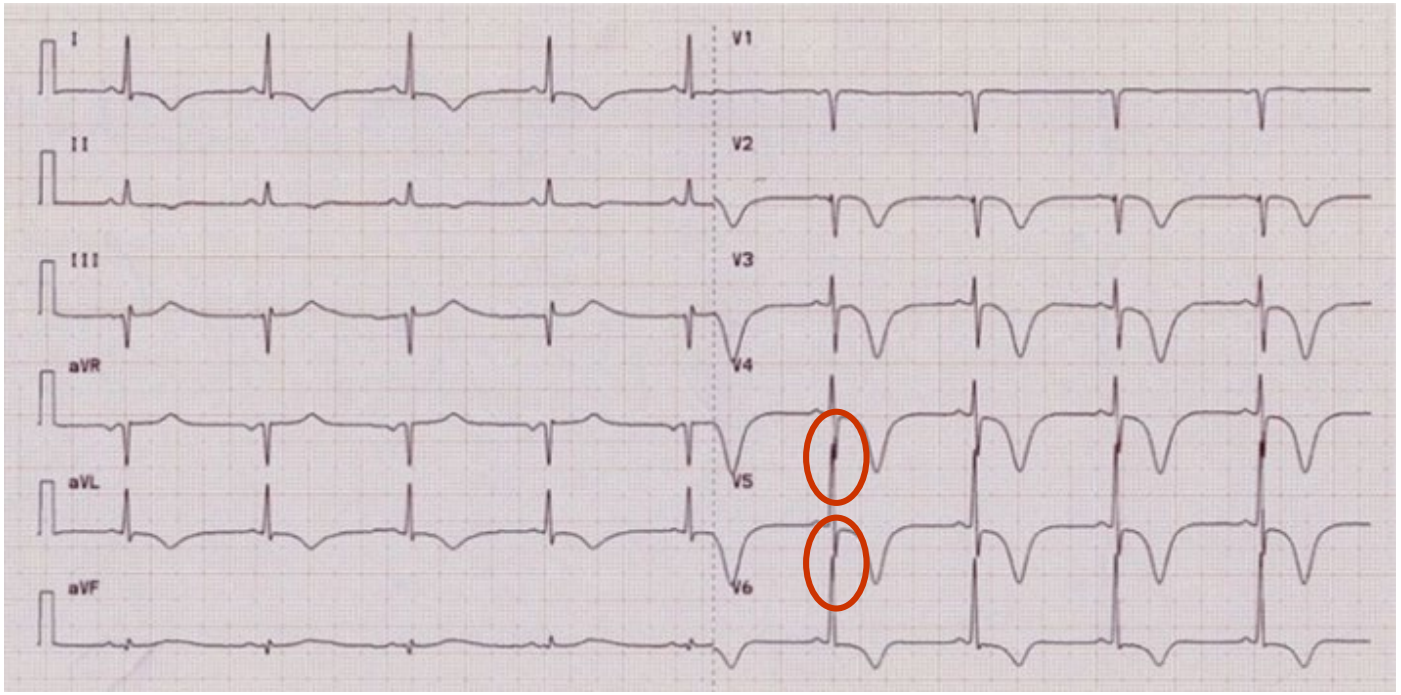
- Standard positions – six leads:
  - V_1, V_2, V_3, V_4, V_5, V_6
  - Standard, well defined positions in the 4th and 5th intercostal space
- Next used locations:
  - V_7
    - Posterior axillary line
  - V_3R, V_4R, V_5R, V_6R
    - „Mirror image“ V_3, V_4, V_5, V_6

Standard 12-lead electrocardiogram (1)



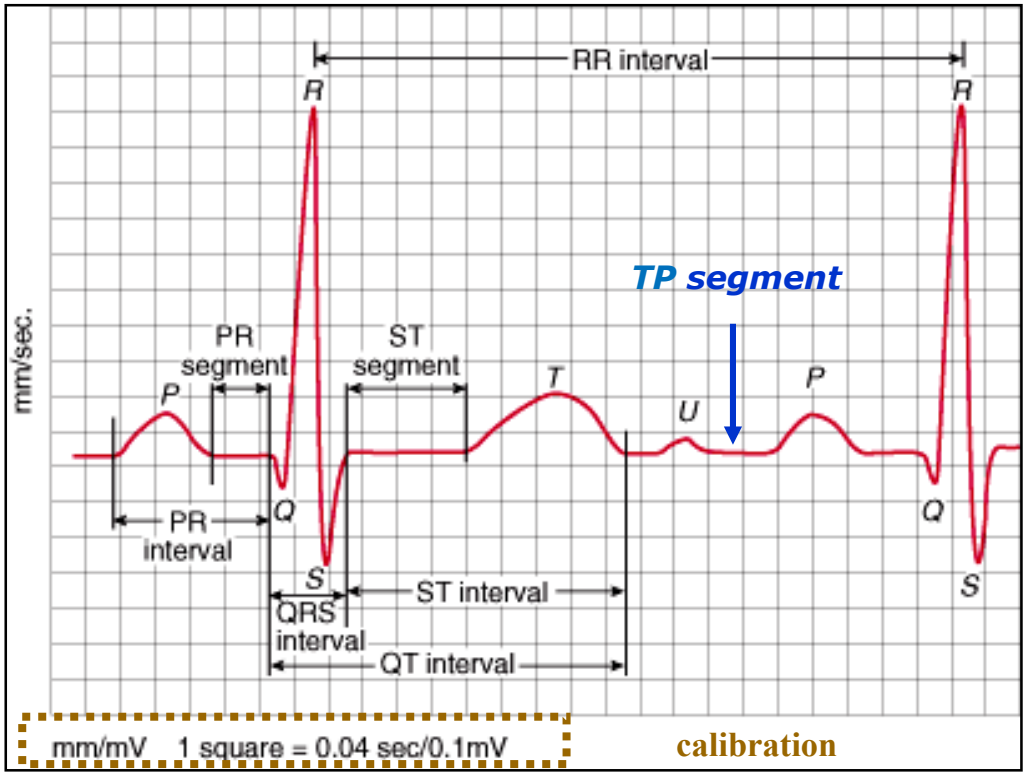
- Displayed are leads I, II, III, aVR, aVL, aVF (left) and V_1 to V_6 (right)
- At the beginning of every lead is the calibration deflection
- Below the curves is paper speed, voltage calibration, registered frequency band of signals and the heart rate
- Source: author's archive

Standard 12-lead electrocardiogram (2)



- Displayed are the leads I, II, III, aVR, aVL, aVF (left) and V_1 to V_6 (right)
- At the beginning of the limb lead is a calibration deflection valid also for the chest lead
  - For leads V_5 and V_6 an appropriate calibration was used – the curves overlap
- Time calibration is missing
- Source: author's archive

Basic terminology of an ECG curve



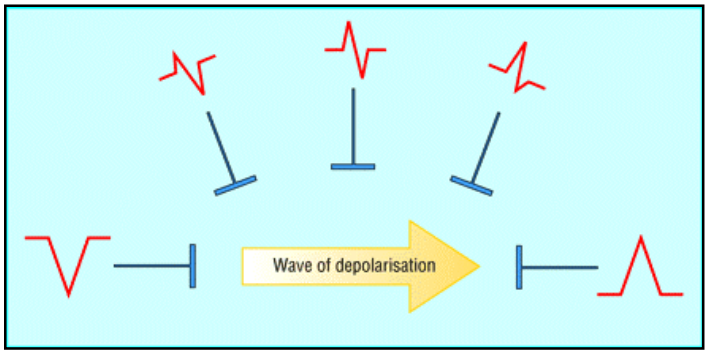
Electrocardiographic terminology. [Cit. 30. 3. 2011]
Available at: http://nursingpub.com/12-lead-ekg-explained-part-1

TP segment is used as zero isoelectric line (zero voltage).

Polarity and height of deflection

- Polarity of deflection
  - Depends on mutual position of the depolarisation wave and the recording electrode

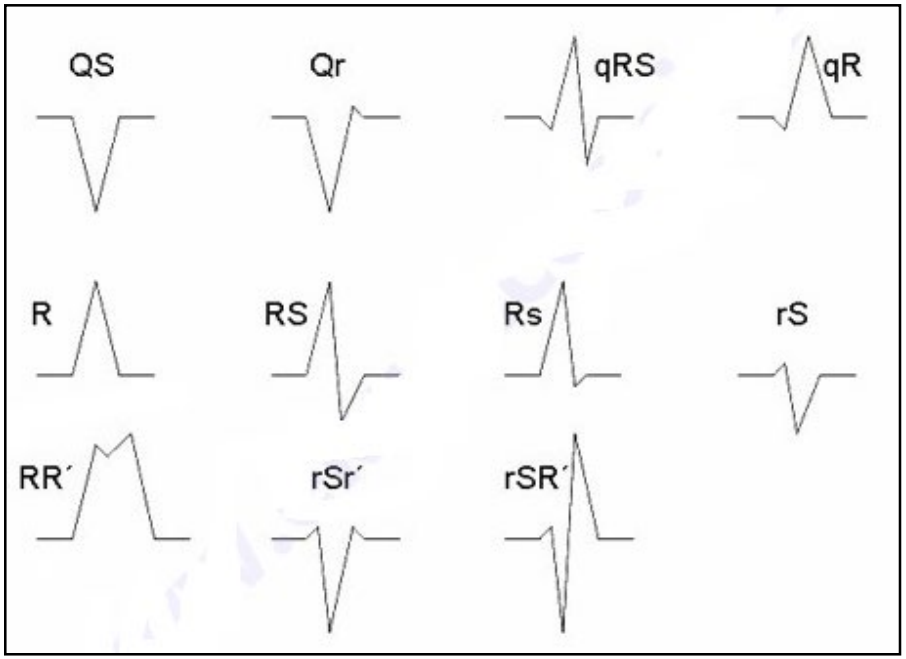
Basic forms of QRS complex according to the polarity. [Cit. 30. 3. 2011] Available at: http://drkupe.blogspot.com/2011/03/ecg.html



- Height of deflection
  - Depends on mutual distance of the depolarisation wave and the recording electrode
  - It is the higher the closer they are
- Depolarisation wave
  - Boundary between polarised and depolarised areas, the direction of depolarisation

Positive and negative waves

- Always positive:
  - Wave R
- Always negative:
  - Wave Q
    - Precedes the R wave
  - Wave S
    - Follows the S wave
- Positive or negative:
  - P wave
  - T wave

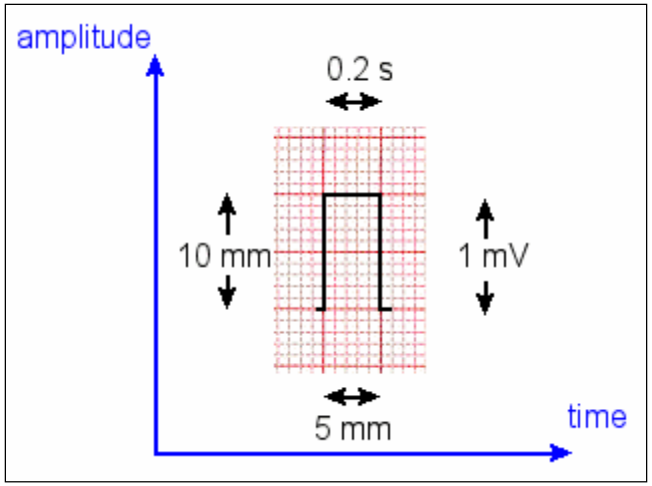


Some possible shapes of QRS complex

© Katarína Kozlíková, 2016

Calibration of the graphic record (1)

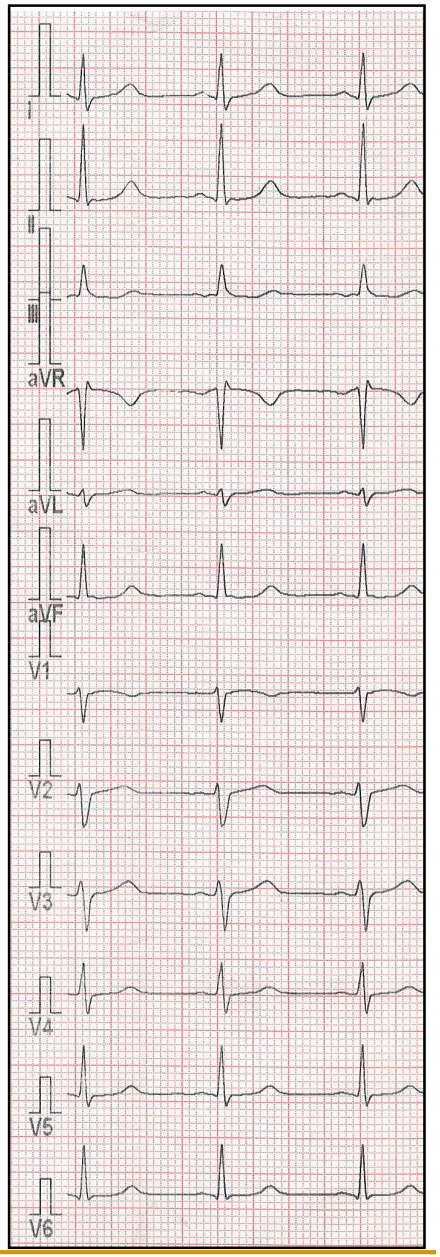
- Electrocardiographic curve is recorded onto a special millimetre paper
- Time calibration – paper speed
  - Standard speed
    - 25 mm/s
      - 1 mm ⇔ 0.04 s
      - 5 mm ⇔ 0.2 s
  - Slower speed (for detailed analysis)
    - 50 mm/s
      - 1 mm ⇔ 0.02 s
      - 5 mm ⇔ 0.1 s
  - Faster speed (for heart rate analysis)
    - 10 mm/s
      - 1 mm ⇔ 0.1 s
      - 5 mm ⇔ 0.5 s



An example of standard calibration

Calibration of the graphic record (2)

- Voltage calibration
  - Standard
    - 10 mm ⇔ 1 mV
      - 1 mm ⇔ 0.1 mV
  - For low deflections
    - 20 mm ⇔ 1 mV
      - 1 mm ⇔ 0.05 mV
  - For high deflections
    - 5 mm ⇔ 1 mV
      - 1 mm ⇔ 0.2 mV



Examples of different voltage calibration for limb leads (10 mm/mV) and for chest leads (5 mm/mV). Source: author's archive

Heart rate (1)

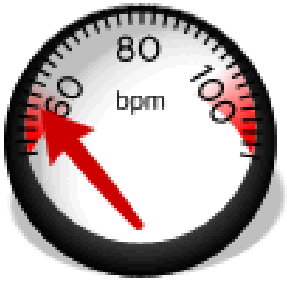
- The pressure wave that passes during the heart activity through the arterial part of the vascular system, is called heart rate (pulse) and is palpable on the arteries
- This series of waves corresponds to the heart rate and frequency
- Measurement of heart rate
  - Palpation method – „on-line“
    - Common way
    - Is considerably subjective
  - Based on an electrocardiographic curve – „off-line“
    - Duration of RR interval
    - More exact measurement

$$SF\ \left[\text{min}^{-1}\right] = \frac{60}{RR\ \left[\text{s}\right]}$$

© Katarína Kozlíková, 2016

Heart rate (2)

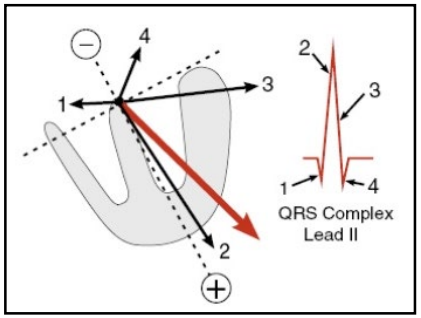
- Heart rate of a healthy person is in average 70 beats/min
  - Physiologic values are 60 beats/min to 90 beats/min
    - Bradycardia – less than 50 beats/min
    - Tachycardia – more than 100 beats/min
- Values can change depending on
  - Age
  - Body size
  - Cardiac problems
  - Physical activity

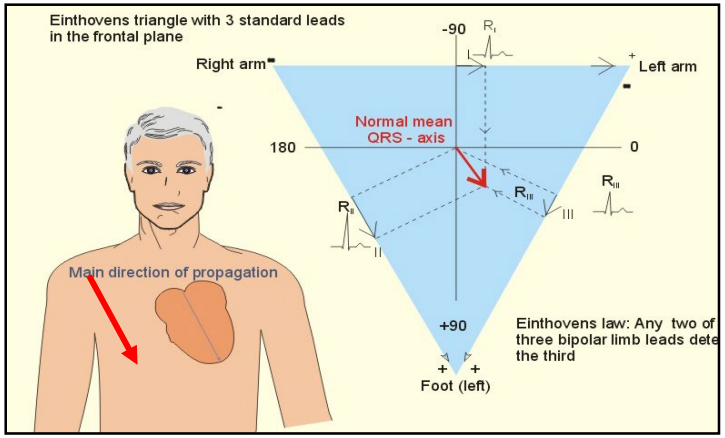


- In persons breathing normally, the heart rate changes
  - Sinus arytmia - physiologic phenomenon
    - Increases during inspiration
    - Decreases during expiration

Electrical heart axis (1)

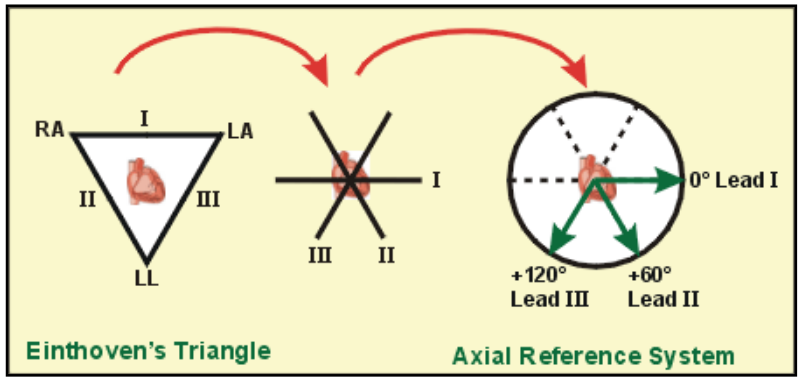
- Represents the dominant direction of propagation of heart activation (not the heart position)
- Direction (orientation) of a vector, that is the sum of all partial vectors during depolarisation
- Mean electric heart vector
- Can be evaluated
  - In a particular time instant (1, 2, 3, 4)
  - During a particular time interval (1+2+3+4)
    - During QRS complex
    - During T wave
    - During P wave



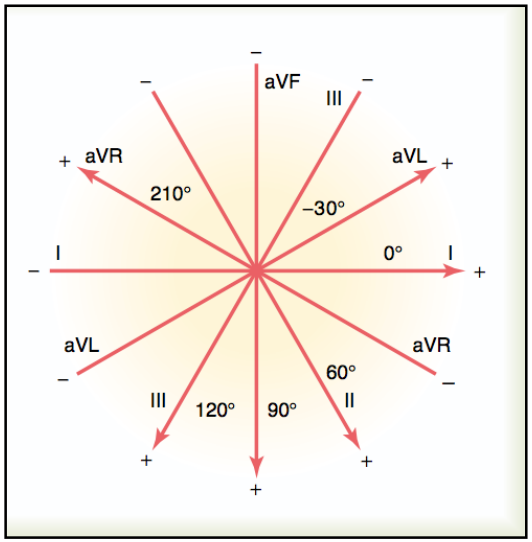


Electrical heart axis (2)

- Usually evaluated in the frontal plane
- Based on
  - Einthoven triangle
  - **Hexaxial reference** (Bailey) **system**
    - Sides of the Einthoven triangle are shifted into its middle

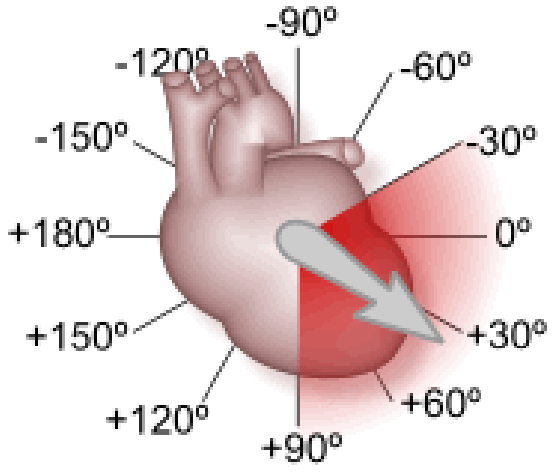


Axial reference system in frontal plane. [Cit. 30. 3. 2011]. Available at: http://www.cvphysiology.com/Arrhythmias/A013a.htm



Electrical heart axis (3)

- Is expressed as an angle measured in degrees from the horizontal axis directed from right to left
  - Types of electrical heart axis
    - Normal
      - - 30° to 100°
    - Left axis deviation
      - - 90° to - 30°
    - Right axis deviation
      - 100° to 180°
    - Extreme right axis deviation
      - - 90° to - 180°
  - Position of electrical heart axis
    - Horizontal
      - - 30° to 30°
    - Vertical
      - Around 90°
    - Intermediate
      - 30° to 60°

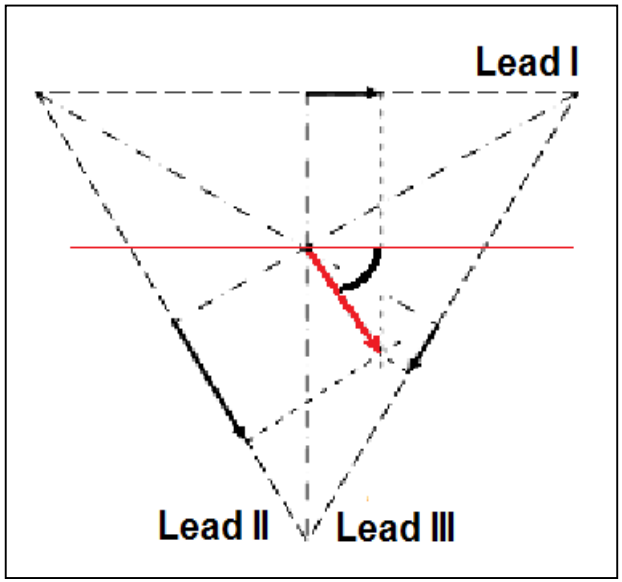


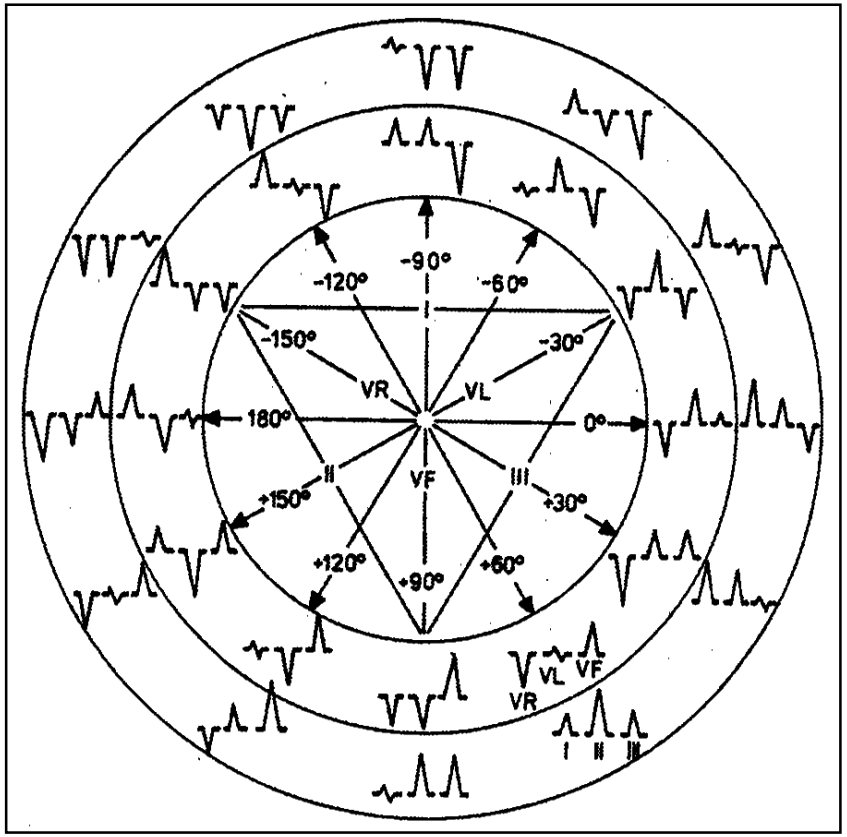
Normal axis

Electrical heart axis. [Cit. 30. 3. 2013] Available at: http:// www.blobs.org/science/article.php?article=87

Electrical heart axis (4)

- Simple visual evaluation based on amplitudes of limb leads
  - I, II, III
  - aVR, aVL, aVF
- Basic principle of construction

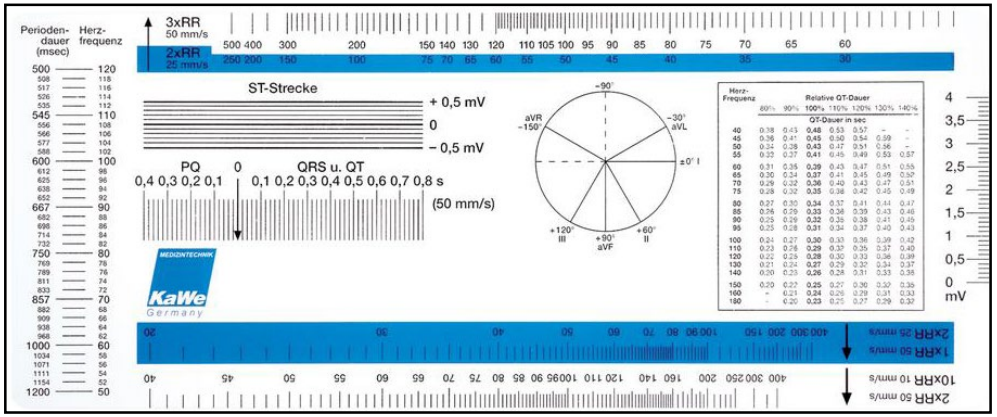


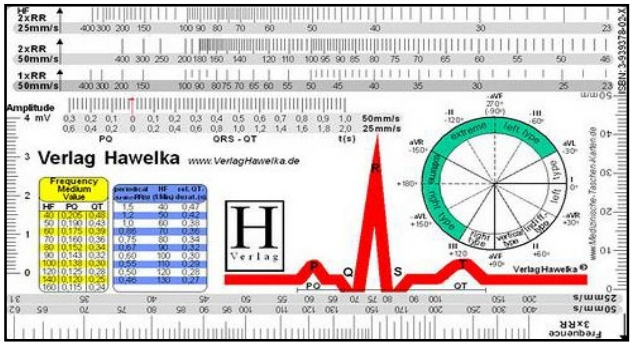


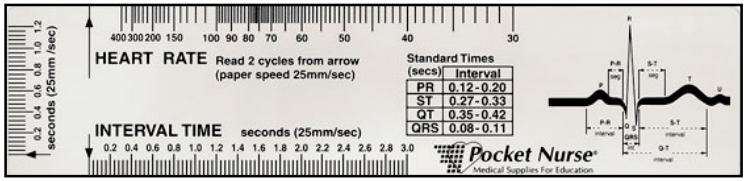
© Katarína Kozlíková, 2016

An ECG ruler – a tool for ECG analysis

- Different versions
  - Always contain
    - Millimetre scale
      - Deflections
      - Time intervals
    - Heart rate scale
    - Time calibration
- May contain
  - Conversion of values
  - Hexaxial system for electrical heart axis evaluation
  - Protractor
  - ECG curve
  - Other data







© Katarína Kozlíková, 2016

Used and recommended literature

Lectures available at MEFANET portal, English version, part Biophysics (http://portal.fmed.uniba.sk/):

K. KOZLÍKOVÁ: *Overview of Biological Signals.*

K. KOZLÍKOVÁ: *Active Electric Biosignals I.*

K. KOZLÍKOVÁ: *Active Electric Biosignals II.*

J. MALMIVUO, R. PLONSEY: *Bioelectromagnetism - Principles and Applications of Bioelectric and Biomagnetic Fields.*

Oxford University Press, New York, 1995, 512 pp. ISBN: 0195058232. [Cit. 19.4.2010] also available in electronic form at: http://www.bem.fi/book/.

© Katarína Kozlíková, 2016